PARASITOLOGY SURVEY OF STONE'S SHEEP (*OVIS DALLI STONEI*) FROM THE MUSKWA-KECHIKA MANAGEMENT AREA, 2000-2002

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Summary

In 2000-2002, a total of 408 fecal samples were collected from Stone's Sheep (*Ovis dalli stonei*, British Columbia species code M-OVDA-ST) in the Muskwa-Kechika Management Area, British Columbia. These samples were analyzed for parasites at the Western College of Veterinary Medicine. The Muskwa-Kechika population did not have unusual levels of parasitism when compared to other wild sheep populations, although there were some differences in parasite fauna and seasonal patterns in parasite shedding. Recommendations for the future include definitive identification of adult parasites, targeted monitoring of the Sentinel herd, and expanded population health monitoring. This is the first description of parasite species, prevalence, and intensity in fecal samples from Stone's Sheep.

Goals

1. To determine which parasites may be present in the population of Stone's Sheep in the Muskwa-Kechika region.
2. To determine current levels of parasite shedding (as a baseline) in Stone's Sheep in the Muskwa-Kechika region.
3. To compare parasite shedding among herds in the Muskwa-Kechika Management Area, and among other wild sheep populations.

Introduction

Approximately 85% of the world population of Stone's Sheep occurs in British Columbia (BC), the majority of which occur in the northeast to central part of the province in and adjacent to the Muskwa-Kechika Management Area (MKMA). Therefore, management of Stone's Sheep is largely the responsibility of BC wildlife management authorities. Apart from the responsibility to manage this wildlife species as an important part of northern biodiversity, sustainable harvesting of Stone's Sheep is also an important source of revenue for residents in northern BC. Recently, a perceived decline in the Muskwa-Kechika Stone's Sheep population has raised public and stakeholder concern for the species. This concern highlights a general lack of knowledge on the health status of Stone's Sheep. In fact, the health status of Thinhorn Sheep in Canada has only recently been investigated in detail, and this work primarily focused on Dall's Sheep (*Ovis dalli dalli*) in the Mackenzie Mountains, Northwest Territories (NT).

In the summer of 2000, this project was proposed as a first step to evaluate the health of Stone's Sheep in the MKMA. A non-invasive fecal collection technique was chosen to investigate the parasites of Stone's Sheep (*Ovis dalli stonei*). This technique has been used for wild sheep populations in North America to varying degrees since parasites play a role in wild sheep health. Fecal surveys for parasites provide a general picture of the parasites present in a population and the levels of parasite shedding, without having to kill animals to recover parasites. While they do have limitations, fecal surveys are a useful preliminary step, particularly if large numbers of samples are available and results can be compared to other wild animal populations. The project was particularly timely as a concurrent three-year study investigating seasonal patterns in parasite shedding was ongoing in a Dall's Sheep population in the Mackenzie Mountains, NT, as well as an investigation of the geographic distribution of a newly recognized parasite (*Parelaphostrongylus odocoilei*) of Thinhorn Sheep in North America. In addition, although there is almost no published information on parasites of Stone's Sheep, two large parasite collections in the 1970s in Dall's Sheep in Alaska and the NT provided an excellent basis for comparing and interpreting results of the current MKMA study.

Methods

We analyzed a total of 408 fecal samples from Stone's Sheep from three herds: Stone Range, Sentinel Range, and Terminal Range in the Muskwa-Kechika Management Area (Stone Mountain and Muncho Lake Provincial Parks), ranging from 58°33.86 to 59°53.5 North, and 124°33.08 to 127°05.00 West (Table 1). Samples were collected as fresh as possible and frozen, or collected frozen and maintained at –20°C in individual Ziploc bags until processing. We also analyzed 22 air-dried samples; however, results were not reported because of poor larval and egg recovery, and most eggs were dead or larvated, making identification difficult. Five grams from each fecal sample were used in both a Wisconsin fecal flotation (Cox and Todd 1962) and modified beaker Baermann larval sedimentation (Forrester and Lankester 1997) in order to quantify the parasite eggs and larvae present. Larvae were counted in 3 aliquots (usually 0.05 ml) of the Baermann sediment on a slide under a compound microscope, and converted to larvae per gram of wet feces (adapted from Beane and Hobbs 1983). If very few or no larvae were detected using the aliquot technique, the entire sediment was examined in a gridded Petri dish or on a slide and all the larvae counted (Forrester and Lankester 1997). Species of parasite present cannot be identified based on the appearance of eggs or larvae shed in the feces; however, we were able to identify dorsal-spined larvae (DSL) to species using DNA analysis (Jenkins et al. 2004). Eggs of gastrointestinal parasites were identified, based on appearance and size, to genus or family level.

The percentage of samples positive for each type of parasite egg or larva (prevalence), the average number of eggs or larvae per gram of feces (mean intensity), and the range (minimum to maximum number of eggs or larvae per gram of feces) were calculated for each herd and collection period. We compared results among the four collection periods (Summer 2000, Spring 2001, Summer 2001, and Spring 2002), and among the three herds (Stone Range, Sentinel Range, and Terminal Range). Summer collections were August-September in 2000 and July-August in 2001, while both spring collections were in March. We drew on adult parasite identifications from Thinhorn Sheep collected in 1970 in AK and NT to obtain probable identifications for the parasite eggs observed in the feces of Stone's Sheep from the MKMA. We also compared results with similar surveys in Dall's Sheep from the Mackenzie Mountains, NT, California Bighorn Sheep (*Ovis canadensis californiana*) in the Fraser River region of BC, and Rocky Mountain Bighorn Sheep (*Ovis canadensis canadensis*) near Hinton, Alberta.

Results

Parasite species

In fecal samples from Stone's Sheep from the MKMA, we found eggs of the following parasites: *Marshallagia* sp., *Nematodirus* spp., *Trichuris* sp., trichostrongyles (multiple parasites of this family produce identical eggs), *Skrjabinema* sp., *Moniezia* sp., and *Eimeria* spp. As well, we found two types of protostrongylid parasite larvae, dorsal-spined larvae (identified as *Parelaphostrongylus odocoilei* using DNA analysis), and *Protostrongylus* spp. larvae. Using the known parasite fauna of Dall's and Bighorn Sheep, possible species identifications for the parasite eggs and larvae observed in feces of Stone's Sheep are provided in Table 2.

Comparisons among collection periods

The percentage of samples positive for each parasite (prevalence), and the average number of eggs or larvae of each parasite (intensity) were compared among the four collection periods (Figures 1 and 2, Tables 3 and 4). *Marshallagia*, *Nematodirus*, *Trichuris*, *Eimeria*, and the two protostrongylid parasites were present year-round at high prevalence, while trichostrongyles, *Skrjabinema*, and *Moniezia* had lower prevalence and were not present in some collections, especially in spring. Intensities, and sometimes prevalence, were higher in spring for *Marshallagia*, *Nematodirus*, *Trichuris*, and *Eimeria*, while trichostrongyles, *Skrjabinema*, and *Moniezia* had higher prevalence and intensity in the summer collections. Dorsal-spined larvae (DSL of *P. odocoilei*) and larvae of *Protostrongylus* were present at a higher prevalence in samples collected in spring versus summer (80-90% versus 60-70%). The prevalence was similar for the two larval types; however, the intensity of shedding of *Protostrongylus* larvae was consistently higher than that of the DSL.

Comparisons among herds within the Muskwa-Kechika

The prevalence and intensity for each parasite species were compared among the 3 herds for each collection period (Figures 3 and 4, Tables 5 and 6). No samples were collected from the Terminal herd in spring 2001, and fewer samples overall were collected from this herd. There were few differences in prevalence among the three herds (Stone Range, Sentinel Range, and Terminal Range), and those parasites with highest prevalence overall had the highest prevalence within the individual herds. In the collections from summer 2000, spring 2001, and summer 2001, the Stone Range herd had lower levels of parasite shedding, while the Sentinel Range herd had the highest levels of shedding for most parasites. In the spring 2002 collection, however, the Sentinel herd had the lowest levels of parasite shedding, except for *Eimeria* spp.

Comparisons among populations of wild sheep

Based on spring fecal collections, *Marshallagia*, *Nematodirus, Trichuris, Eimeria*, and *Protostrongylus* had high prevalence among all four species and subspecies of *Ovis* (Figure 5). Trichostrongyles had much higher prevalence in the Rocky Mountain

Bighorn Sheep examined. In general, gastro-intestinal parasite shedding was higher in Rocky Mountain Bighorn Sheep from Hinton (based on a very small sample size of 10), and Dall's Sheep had the highest levels of larval shedding (Figure 6). In Stone's Sheep, both DSL and *Protostrongylus* larvae were present at a similar prevalence (overall 77% for both) (Figure 7). In Dall's Sheep, however, DSL were present at high prevalence (90-100%) in all collections and there was a marked decrease in prevalence of *Protostrongylus* larval shedding in August of each year (17 and 32%). In Stone's Sheep, the intensity of shedding was higher for *Protostrongylus* larvae than DSL in all collection periods (Figure 8).

Discussion

This fecal survey represents the first complete description of parasites shed in feces in a population of Stone's Sheep, as well as an initial investigation into the role of parasitism in a declining population within the MKMA of British Columbia. Fecal surveys indicate what parasite species may be present, what percent of the herd is infected (prevalence), and the average number of parasites shed in the feces (intensity). They do, however, have limitations. First, as many parasite species produce eggs and larvae that are indistinguishable, it is only possible to identify the genus or family of the parasites present. Second, prevalence and intensity of parasite shedding is influenced by many factors, including sample age and storage, season of collection, age and sex of sheep, and herd demography: for example, herds with many lambs may have higher levels of parasite shedding because juvenile animals have little immunity to parasites (Uhazy et al. 1973; Festa-Bianchet 1991; Peterson et al. 1996; Forrester and Lankester 1997). Therefore, interpretation is difficult, as higher levels of parasite shedding do not necessarily mean that the herd is infected with higher numbers of parasites or is unhealthy. Finally, in order to draw conclusions, there must be some framework in which to compare prevalence and intensity among different herds and different species of sheep. Using standardized techniques, the veterinary parasitology laboratory at the University of Saskatchewan has analyzed samples collected from a variety of wild sheep populations at known times of year. The unique data from these samples enable us to make meaningful comparisons among these different populations and gain some insights into the significance of parasitism.

Parasite species

Based on the appearance of eggs and larvae in feces of Stone's Sheep, and information on the parasites of Dall's Sheep in Alaska and the Northwest Territories, the parasites likely present in Stone's Sheep in the Muskwa-Kechika region are listed in Table 2 (Clark and Colwell 1974; Neilsen and Neiland 1974; Hoberg et al. 2001; Kutz 2001, Kutz et al. 2001). Parasites that may also be present in Thinhorn Sheep that are thought to be primarily parasites of other wildlife include *Ostertagia gruehneri* from caribou, *Ostertagia ostertagi* from bison, *Teladorsagia davtiani* from caribou, and *Nematodirella alcidis* from moose (Neilsen and Neiland, 1974; Hoberg et al. 2001; Kutz 2001). It is likely that Stone's Sheep share a similar parasite fauna with other Thinhorn Sheep, and with Bighorn Sheep, except for the parasites of domestic animals that have been introduced into many Bighorn Sheep populations - 70% of the 51 species of nematodes reported in Bighorn Sheep are thought to come from domestic sheep, while 55% are thought to come from domestic cattle (Becklund and Senger 1967). Interestingly, in the Stone's Sheep samples (nor in 1600 Thinhorn Sheep samples examined to date), we did not find eggs of the bile duct tapeworm, *Wyominia tetoni*, which is common in Rocky Mountain Bighorn Sheep in BC (Schwantje 1988) and has been reported in Thinhorn Sheep in the Yukon Territory (Gibbs and Fuller 1959).

Larvae of *Protostrongylus* spp. (sheep lungworm) were present in Stone's Sheep in the MKMA, consistent with previous reports in Stone's Sheep near Toad River and Atlin, BC (Seip and Bunnell 1985; H. Schwantje, unpubl. data 1994). These larvae are likely *P. stilesi* and/or *P. rushi*; both produce indistinguishable larvae and have a widespread distribution in Bighorn and Thinhorn Sheep populations (Goble and Murie 1942; Uhazy et al. 1973; Kutz et al. 2001; Jenkins et al. 2004). DNA analysis indicates that dorsal-spined larvae (DSL) in Stone's Sheep feces in the Muskwa-Kechika region as well as samples from the Spatsizi Plateau, west of the MKMA, were the muscleworm *Parelaphostrongylus odocoilei* (Jenkins et al. 2004). DSL have been reported in Stone's Sheep near Toad River, but were thought to be those of *Muellerius capillaris*, the lungworm of domestic sheep and goats (Seip and Bunnell 1985). *Parelaphostrongylus odocoilei* is established in Thinhorn Sheep at a variety of locations in Alaska, the Yukon, the Northwest Territories, and British Columbia (Kutz et al. 2001; Jenkins et al. 2004). Interestingly, in a separate study, no DSL were recovered from 55 fecal samples from a small population of Stone's Sheep near the Williston Reservoir (Jenkins et al. 2004; M. Wood, unpubl. data), which suggests that isolated herds may not have been exposed to this parasite.

Comparisons among collection periods

There were differences in parasite prevalence and intensity between the collection periods consistent with patterns observed in other wild sheep populations; however, we only sampled the Muskwa-Kechika Stone's Sheep population in spring and summer. Therefore, it is not possible to obtain a complete picture of seasonal patterns of parasite shedding in this population.

Of the gastro-intestinal nematodes, *Marshallagia* was the most prevalent, and maintained this high prevalence year-round, as has been reported in Thinhorn and Bighorn Sheep (Uhazy and Holmes 1971; Neilsen and Neiland 1974; Kistner et al. 1977). The majority of parasites had higher intensities in spring than summer. This "spring rise" in parasite shedding is also present in Dall's Sheep in the Mackenzie Mountains, and is a well-documented phenomenon in many wild and domestic hosts. It is thought to be due to a combination of poor host immunity (due to nutritional stress at the end of winter and advanced pregnancy in the females) and a strategy on the part of the parasite to heavily contaminate range just prior to summer, the season of parasite development outside of the sheep host, and transmission to new hosts.

Trichostrongyle, *Skrjabinema*, and *Moniezia* eggs were exceptions to the "spring rise", as they were present at highest prevalence and intensity in the summer samples. This has been reported for trichostrongyles in Dall's Sheep in Alaska (Neilsen and Neiland 1974) and California Bighorn Sheep from the Fraser River area, BC (H.

Schwantje and E. Jenkins, unpubl. data), and probably reflects different life history strategies of these parasites. In some collection periods, especially when fewer samples were collected (i.e., spring 2001), eggs of these less prevalent species were not recovered from any samples. Fecal parasite prevalence has, however, been shown to be much less than prevalence based on adult parasite recovery, especially for the trichostrongyles (Uhazy and Holmes 1971).

The coccidian parasites (*Eimeria* spp.) were present at high prevalence and intensity year-round, as is the case in both Bighorn and Dall's Sheep (Uhazy et al. 1971; E. Jenkins et al., unpubl. data). Despite this, there is no evidence that clinical coccidiosis occurs in wild sheep, even at much higher intensities (up to 76,000 eggs per gram of feces) (Uhazy et al. 1971).

Comparisons among herds within the Muskwa-Kechika

In general, parasite prevalence varied little among the three herds in the MKMA (Stone Range, Sentinel Range, and Terminal Range). In 2000 and 2001, the Sentinel herd had higher intensities of shedding of some parasites than the other herds. While interpretation of parasite shedding as a measure of herd health is somewhat controversial, it is possible that the Sentinel herd had a higher number of more heavily infected individuals. This could be due to localized range conditions, or perhaps environmental stress in the period between summer 2000 and summer 2001. The fact that parasite shedding dropped in this herd in spring 2002 could indicate that the problem had resolved, or that heavily parasitized individuals in the Sentinel herd were not sampled or died overwinter and did not contribute to the samples in spring 2002. More evaluation of the demographics of this herd and further monitoring of parasite levels are indicated.

Comparisons among populations of wild sheep

While the core parasite fauna of wild sheep in North America is similar among the various species of *Ovis*, we observed a few notable differences in the presence, prevalence, and seasonal patterns of parasite shedding among the various populations. For example, dorsal-spined larvae of *P. odocoilei* were only present in Thinhorn Sheep; sporadic reports of DSL in Bighorn Sheep have so far proved to be *Muellerius capillaris* or, in at least one instance, an accidental inclusion of mule deer fecal samples positive for larvae of *P. odocoilei* with sheep samples (Jenkins et al. 2004). As well, eggs of the bile duct tapeworm *Wyominia* were observed in this study only in California Bighorn Sheep, and trichostrongyles had much higher prevalence in the Rocky Mountain Bighorn Sheep examined.

There were also differences in the seasonal dynamics of the two protostrongylid parasites between the current study and the three-year investigation of Dall's Sheep in the Mackenzie Mountains. In Stone's Sheep, the lungworm *Protostrongylus* appears to dominate, with consistently higher larval shedding than DSL. In the Dall's Sheep, DSL dominate, with higher prevalence and intensity year-round than *Protostrongylus* larvae. A clear seasonal pattern is present in Dall's Sheep, with a spring peak in both protostrongylid parasites and a marked summer decline in *Protostrongylus* larval prevalence and intensity. While there is some evidence that there was a spring peak in larval shedding by Stone's Sheep in the spring of 2001, both protostrongylids had low shedding in spring 2002. As the timing of the spring peak in larval shedding may vary annually, it is possible that we missed it in spring 2002 when collecting over a two day time period. The Dall's Sheep study collected fecal samples every two months so was able to more accurately describe the timing of peak parasite shedding.

Differences in fecal parasite prevalence and intensity among sheep populations are very difficult to interpret. Differences may be due to variation in host susceptibility, host density, parasite establishment and transmission due to habitat and climate differences, timing of seasonal cycles, and, in some bighorn populations, the use of deworming medications. Such differences rarely correlate with the health status of a population. For example, gastro-intestinal parasite shedding in the Rocky Mountain Bighorn Sheep was higher than the other populations, and yet this population (near Hinton, Alberta) is considered healthy and is used as a source herd for translocation to recover populations at risk. Dall's Sheep from the Mackenzie Mountains had the highest larval counts of both lungworm and muscleworm, and Thinhorn Sheep collectively shed *Protostrongylus* larvae at higher intensities than many Bighorn Sheep populations; despite this, Thinhorn Sheep in the Mackenzie Mountains and elsewhere are considered to be healthy, with no evidence of a decline or disease-related die-offs (Veitch and Simmons 1999).

Implications for sheep health

Unlike health management programs for domestic livestock, there are no defined "danger thresholds" for parasite shedding in wild sheep; therefore, it is very difficult to determine what constitutes an unacceptably high level of parasite shedding (Neilsen and Neiland 1974). At this time there do not appear to be high levels of gastro-intestinal parasitism in Stone's Sheep. In other wild and domestic host populations, however, species of these parasites have been associated with poor body condition, low pregnancy rates, and increased occurrence of concurrent disease, as well as decreased appetite, weight loss, diarrhea, and poor hair coats (Uhazy and Holmes 1971; Neilsen and Neiland 1974; Kutz 2001). The negative effects of parasitism are most often seen in late winter/early spring, when shedding peaks for many parasites and animals are often undernourished. Certain gastro-intestinal parasites are more likely to have significant impacts on the health of wild sheep. High burdens of *Marshallagia*, abundant in most sheep populations, may be linked to stomach ulceration and decreased body condition (Uhazy and Holmes 1971; Kutz 2001). The whipworm *Trichuris* can cause nodules in the lining of the large intestine and may be an important parasite in lambs, as could *Nematodirus oiratianus* (Neilsen and Neiland 1974; Kistner et al. 1977). Infection levels of these more pathogenic gastrointestinal parasites may be more useful indicators of herd health than overall levels of parasitism.

At least two species of protostrongylid parasites are established in the Muskwa-Kechika Stone's Sheep population, and will be of particular interest to wild sheep managers. *Protostrongylus* spp. lungworms have been associated with a fatal pneumonia complex in Bighorn Sheep since at least the early part of the 20th century. Current research and disease investigations, as well as responses to management actions, indicate that the role of lungworm in bighorn pneumonia should be considered as one of a number of factors pre-disposing animals to poor health. Additional factors including human disturbance, habitat condition, extremes of weather, and the presence of infectious organisms such as *Mannheimia/Pasteurella* spp., especially those from contact with domestic sheep, are believed to collectively contribute to this disease complex. During its life cycle, the eggs and larvae of *Parelaphostrongylus odocoilei* pass through sheep lungs and are associated with tissue damage in both naturally and experimentally infected Thinhorn Sheep (Kutz et al. 2001). This parasite also caused emaciation and temporary neurological signs in experimentally infected sheep (E. Jenkins, unpubl. data). The potential of synergistic lung damage caused by *P. odocoilei* and *Protostrongylus* spp. may create a unique health risk for Thinhorn Sheep.

All the evidence suggests, however, that Thinhorn Sheep populations are in fact quite healthy, especially in comparison to Bighorn Sheep in southern ranges. Thinhorn Sheep live in large continuous habitats, and have minimal exposure to domestic animal pathogens or human-related stressors. There have been no reports of large scale outbreaks of disease in Thinhorn Sheep, despite the sporadic occurrence of pneumonia and evidence of lung damage caused by parasites (Bowyer and Leslie 1992; Jenkins et al. 2001; Kutz et al. 2001). However, should Thinhorn Sheep be exposed to the same stressors and infectious organisms that have contributed to declines in Bighorn Sheep populations in western North America, there is every reason to anticipate disease outbreaks and die-offs in the north. Thinhorn Sheep inhabit a northern environment with regular climatic extremes, and are subject to the stresses associated with natural predation, human harvest, and, in some cases, industrial exploration and development (Heimer et al. 1992). The delicate balance among Thinhorn Sheep, their parasites and diseases, and the northern environment could be disturbed by global temperature increases more favorable for parasite transmission, increased stress from higher levels of habitat and human related disturbances, and exposure to domestic animal pathogens. It is imperative that baseline information is collected from northern ecosystems such as Thinhorn Sheep in the MKMA before such factors cause irreversible changes.

Recommendations

1) Stone’s Sheep in the Muskwa-Kechika Management Area did not have an unusually high prevalence or intensity of parasite shedding relative to other wild sheep populations examined; therefore, no management actions to control parasitism are deemed necessary.
2) The discovery of *P. odocoilei* in this population and the absence of other reports on parasites of Stone’s Sheep indicate how little is known about the parasite fauna of this valuable species. We need to take the next step to determine the full spectrum of parasites present in Stone’s Sheep. This can only be accomplished by recovering adult parasites from several carcasses, which is necessary to conclusively identify parasite species.
3) The following parasite monitoring program is recommended:
    a. Target the Sentinel Range herd, which had higher levels of shedding of some parasites.
    b. Follow one sheep population throughout the year with fecal samples taken at regular intervals to allow the identification of seasonal patterns; this

allows targeting of future sampling to maximize chances of parasite recovery, and to predict when parasites are most likely to cause damage and resultant disease.
   c. Collect fecal samples from marked animals of known age and sex in order to determine the demographic groups most affected by parasitism.
4) Both healthy and diseased animals examined on an opportunistic and targeted basis could form a baseline database as part of a Stone's Sheep "herd health program" for the MKMA. This database will help to:
   a. Determine what role parasitism plays in the health of this population.
   b. Determine whether other infectious organisms and potential pathogens are present.
   c. Detect changes in the health of the population, the first step in anticipating and preventing problems.
5) Contact with domestic animals, especially sheep and cattle, is not recommended as Stone's Sheep in the MKMA probably harbour only parasites adapted to this species. They are likely to be susceptible to parasites of domestic animals, based on evidence of transmission between Bighorn Sheep and domestic livestock elsewhere. If contact is unavoidable, risk assessments carried out in advance, and cooperation between wildlife stakeholders and domestic animal owners are necessary to minimize impacts on both wild and domestic animals.
6) In summary, fecal parasite monitoring can be a useful indicator of population health if there is an established baseline, and if they are used in conjunction with other indicators of population health (Schwantje 1988).
7) Wildlife management decisions based on sound science involve long term studies to establish baselines, and early detection of population declines and disease outbreaks.
8) Cooperation among wildlife stakeholders, including First Nations, outfitters, resident hunters, wildlife veterinarians, wildlife biologists, and local communities, is key to effectively managing the valuable Stone's Sheep population in the MKMA.

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Table 1: Number of fecal samples collected from Stone's Sheep from the Muskwa-Kechika region, 2000-2002.

Collection period	Stone	Sentinel	Terminal	Unknown	Total
Aug 14-Sept 20, 2000	47	32	6	14	99
Mar 22-26, 2001	17	19	0	0	36
July 24-Aug 2, 2001	73	73	14	2	162
Mar 12-14, 2002	34	30	24	23	111
Total	171	154	44	39	408

Table 2: Types of eggs and larvae found in fecal samples from Stone's Sheep from the Muskwa-Kechika region, and possible identifications based on the known parasite fauna of Thinhorn Sheep.

(from Neilsen and Neiland 1974; Hoberg et al. 2001; Kutz 2001)

M-K Stone's (abbreviations used in this report)	Location and parasite type	Parasites of Thinhorn Sheep
Marshallagia sp. (Marsh)	Abomasum (true stomach) Nematode	*Marshallagia marshalli/ M. occidentalis*
Trichostrongyle type eggs (Tricho)	Abomasum(true stomach) Nematode	*Ostertagia* sp., *Teladorsagia* spp.
Nematodirus spp. (Nem)	Small intestine Nematode	*Nematodirus andersoni, N. archari, N. davtiani, N. spathiger, N. oiratianus*
Trichuris sp. (Tru)	Large intestine Nematode (whipworm)	*Trichuris schumakovitschi*
Skrjabinema sp. (Skrjab)	Large intestine/rectum Nematode (pinworm)	*Skrjabinema ovis*
Moniezia sp. (Mon)	Intestine Tapeworm	*Moniezia* sp.
Eimeria spp. (Eim)	Intestine coccidia (single-celled protozoan)	*Eimeria crandallis, E. ahsata, E. parva, E. ninakohlyakimovae, E. dalli*
Parelaphostrongylus odocoilei (DSL = dorsal-spined larvae)	Muscles Protostrongylid nematode	Present in many, but not all, Thinhorn Sheep.
Protostrongylus spp. (Proto)	Lung tissue and airways Protostrongylid nematode	*Protostrongylus stilesi* and *P. rushi*

Table 3: Fecal parasite prevalence (percent samples that were positive for each parasite) in samples from Muskwa-Kechika Stone's Sheep.

All numbers are percentages except number of samples (n).

	Summer 2000	**Spring 2001**	**Summer 2001**	**Spring 2002**
n	99	36	162	111
Marshallagia	62.6	72.2	80.9	91.9
Nematodirus	47.5	77.8	70.4	81.1
Trichuris	49.5	58.3	44.4	81.1
Trichostrongyle	13.1	0	17.3	13.5
Skrjabinema	8.1	0	4.9	0
Moniezia	19.2	5.6	14.8	10.8
Eimeria	72.7	77.8	85.8	93.7
P. odocoilei	63.6	83.3	70.4	91
Protostrongylus spp.	67.7	83.3	69.8	87.4

Table 4: Fecal parasite average intensity (number of parasites per gram of feces) and range (minimum to maximum) in samples from Muskwa-Kechika Stone's Sheep.

All values in eggs or larvae per gram of feces except n.

	Summer 2000	**Spring 2001**	**Summer 2001**	**Spring 2002**
n	99	36	162	111
Marshallagia	3.7 (0.2-11.4)	7.7 (1.2-39)	5.7 (0.2-28.6)	9 (0.2-136)
Nematodirus	1.2 (0.2-10.8)	3.6 (0.2-26.4)	1.5 (0.2-7.4)	3.4 (0.2-14)
Trichuris	4.8 (0.2-34.2)	6.5 (0.5-44.6)	5.7 (0.2-62.4)	18.4 (0.2-494)
Trichostrongyle	2.6 (0.2-17.2)	0	0.5 (0.2-1.8)	1.02 (0.2-9.3)
Skrjabinema	1.2 (0.2-5)	0	3.4 (0.2-8.8)	0
Moniezia	45.5 (0.3-247.8)	3.4 (2.3-4.6)	69.6 (0.4-269.8)	10.4 (1.8-60.8)
Eimeria	95.3 (0.5-1904.8)	81.7 (0.6-400)	50.7 (0.2-606.1)	132.3 (0.2-2000)
P. odocoilei	36.9 (0.2-445)	133.3 (1.4-1042.2)	98.6 (1.2-729)	83.1 (0.4-601.8)
Protostrongylus	199.8 (0.2-6527)	663.4 (20.9-2312.4)	364.6 (0.4-5923.1)	101.7 (0.6-1207.5)

Table 5: Fecal parasite prevalence (percent samples that were positive for each parasite) for each of the three Stone's Sheep herds in the Muskwa-Kechika region.

All numbers are percentages except number of samples.

	Summer 2000			Spring 2001		Summer2001			Spring 2002		
	Stone	Sentinel	Terminal	Stone	Sentinel	Stone	Sentinel	Terminal	Stone	Sentinel	Terminal
n	47	32	6	17	19	73	73	14	34	30	24
Marsh	75	50	83	77	68	88	77	64	100	80	95.8
Nem	45	34	100	77	79	77	63	71	82.4	66.7	83.3
Tru	49	50	67	59	58	43	43	71	88.2	76.7	58.3
Tricho	13	22	0	0	0	33	6	0	26.5	0	4.2
Skrjab	13	6	0	0	0	6	1	14	0	0	0
Mon	17	16	17	0	11	11	21	7	11.8	10	0
Eim	77	66	83	88	68	95	82	57	100	83.3	100
DSL	62	59	83	82	84	86	56	64	91.2	93.3	100
Proto	66	63	67	82	84	55	80	93	88.2	83.3	95.8

Table 6: Fecal parasite average intensity (number of parasites per gram of feces) for each of the three Stone's Sheep herds in the Muskwa-Kechika region.

All values in eggs or larvae per gram of feces except n (number of samples).

	Summer 2000			Spring 2001		Summer 2001			Spring 2002		
	Stone	Sentinel	Terminal	Stone	Sentinel	Stone	Sentinel	Terminal	Stone	Sentinel	Terminal
n	47	32	6	17	19	73	73	14	34	30	24
Marsh	3	5.1	5.5	8.5	7	4.4	7.6	3.3	4.6	3.8	4
Nem	0.7	1.7	0.7	3.3	3.9	1.6	1.5	0.8	2.5	2.2	2.6
Tru	3.7	4.5	8.2	2.7	10	3.5	9.1	1.9	16.9	7.1	42.1
Tricho	2.1	3	0	0	0	0.4	0.7	0	0.4	0	0.2
Skrjab	1.4	0.7	0	0	0	3	8.8	3.1	0	0	0
Mon	18.3	59.1	247.8	0	3.4	52.1	78.9	70	6.8	5.1	0
Eim	66.2	183.6	61.8	66.5	99.1	62.2	42.4	9.2	55.3	107.7	17.6
DSL	16.4	65.6	70.8	69.2	189.3	89.9	113.2	91.2	84.9	49.3	135.3
Proto	33.1	518.8	393.8	500.5	806	153.4	562	167.7	57.5	15.7	187.6

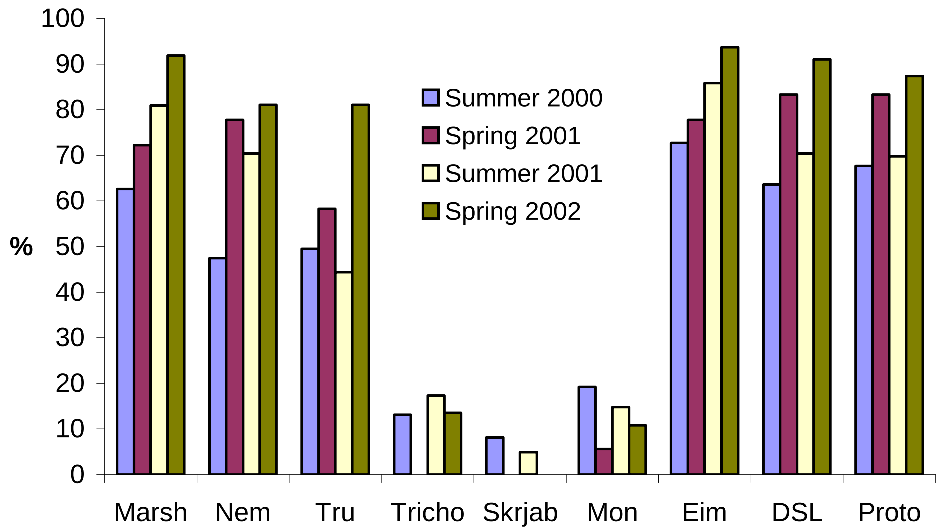

Figure 1: Prevalence (percent samples that were positive for each parasite) in fecal samples from the Muskwa-Kechika Stone's Sheep population in the four collection periods.

Parasite names on the horizontal-axis correspond to Table 2. Values are in Table 3.

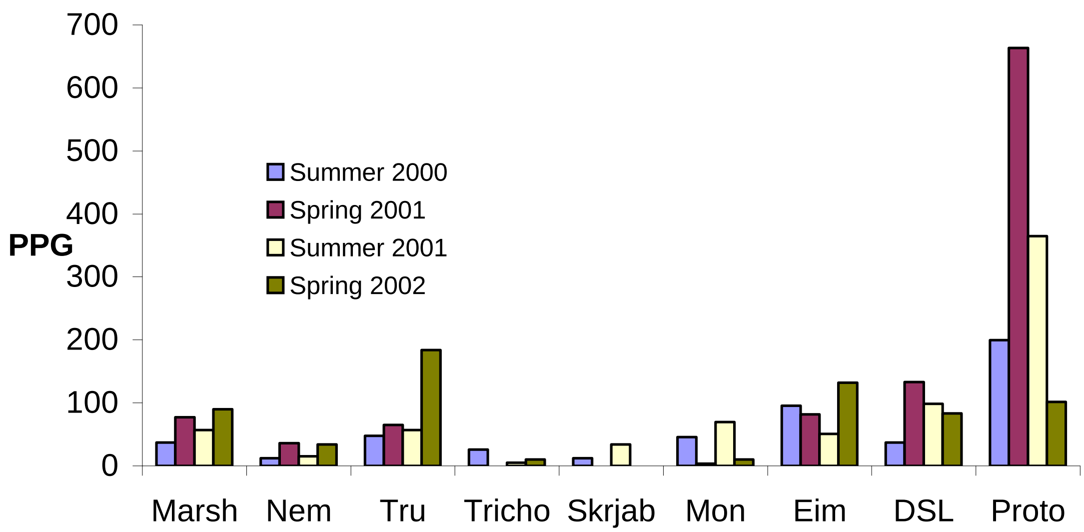

Figure 2: Average intensity (number of parasite eggs or larvae per gram of feces, PPG) of each parasite in fecal samples from the Muskwa-Kechika Stone's Sheep population in the four collection periods.

Parasite names on the horizontal-axis correspond to Table 2. Note that the values for Marsh, Nem, Tru, Tricho, and Skrjab were multiplied by 10 to better demonstrate differences at this scale. Actual values are in Table 4.

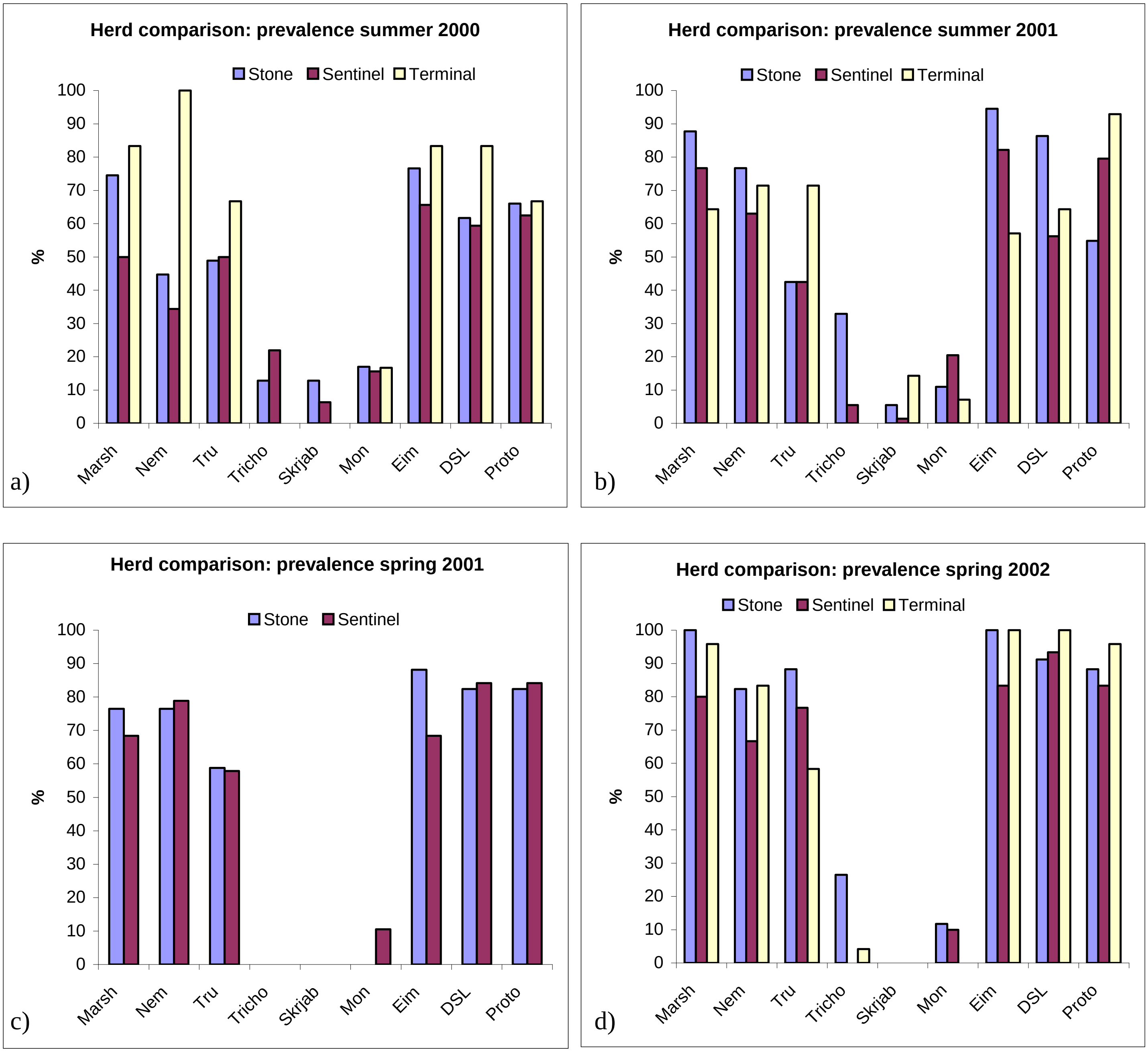

Figure 3: Prevalence (percent samples that were positive for each parasite) among the three herds (Stone Range, Sentinel Range, Terminal Range) over the four collection periods.

a) summer 2000; b) summer 2001; c) spring 2001; and d) spring 2002. Parasite names on the horizontal-axis correspond to Table 2. Values are in Table 5.

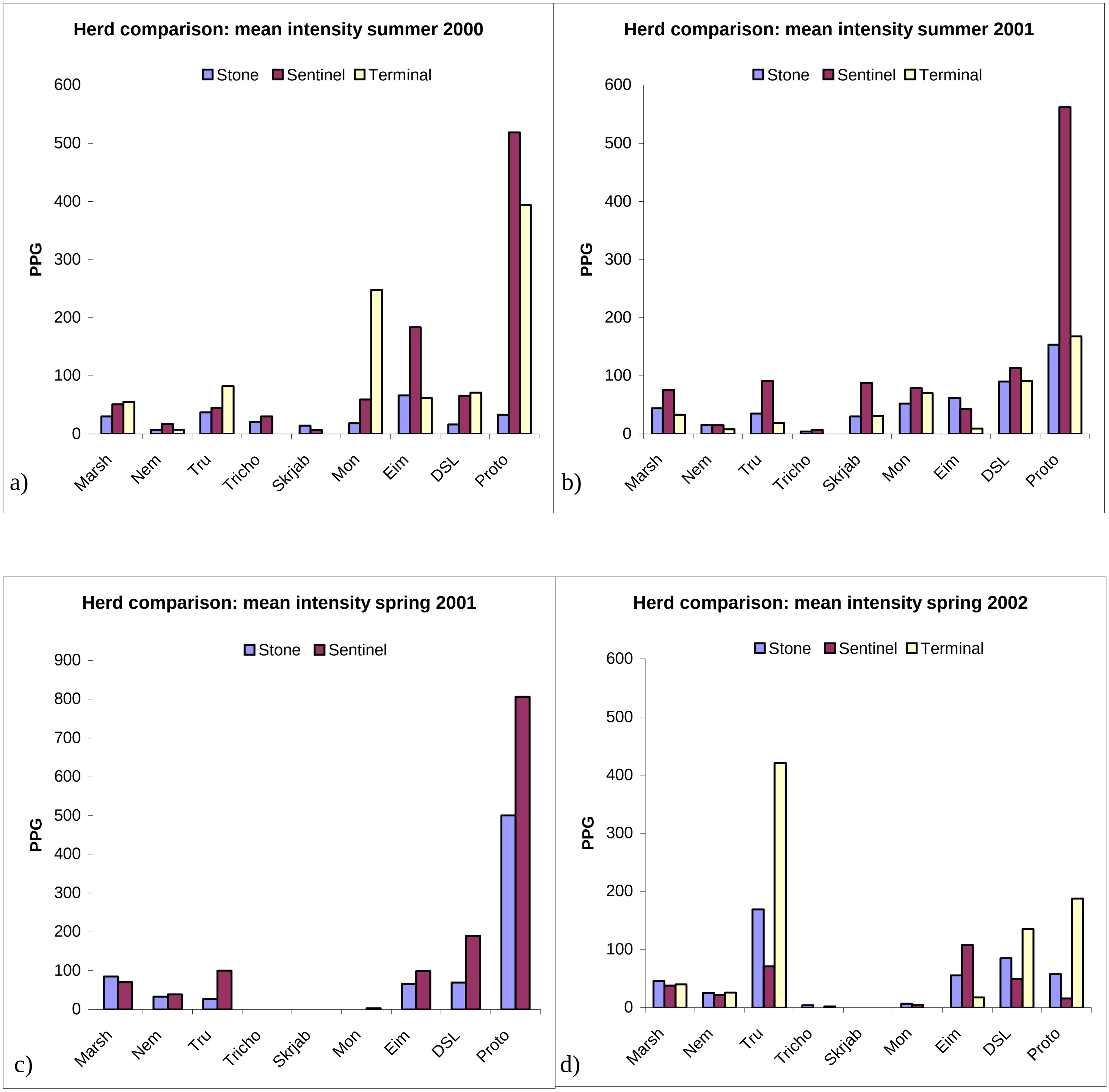

Figure 4: Average intensity (number of parasite eggs or larvae per gram of feces, PPG) among the three herds (Stone Range, Sentinel Range, Terminal Range) over the four collection periods.

a) summer 2000; b) summer 2001; c) spring 2001 (note axis goes to 900 PPG); and d) spring 2002. Parasite names on the horizontal-axis correspond to Table 2; note that values for Marsh, Nem, Tru, Tricho, and Skrjab were multiplied by 10 to better demonstrate differences at this scale. Actual values are in Table 6.

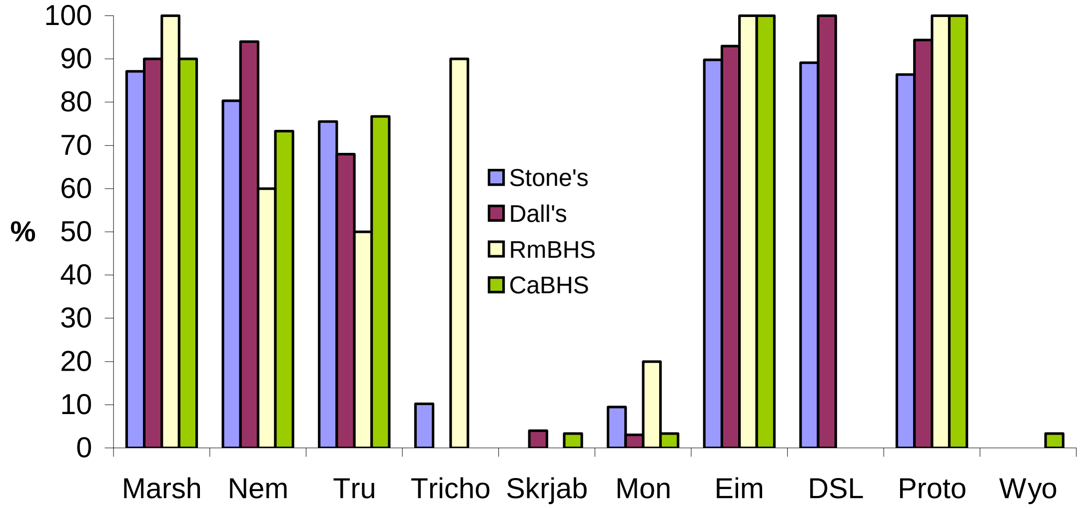

Figure 5: Prevalence (percent samples that were positive for each parasite) from spring fecal collections from 4 wild sheep populations.

For Figures 5 and 6: Stone's pooled Spring 2001 and 2002, n=147; Dall's pooled Spring 2001 and 2002, n=71; Rocky Mountain Bighorn Sheep Spring 2001, n=10; California Bighorn Sheep Spring 2002, n=30. Parasite names on the horizontal-axis correspond to Table 2.

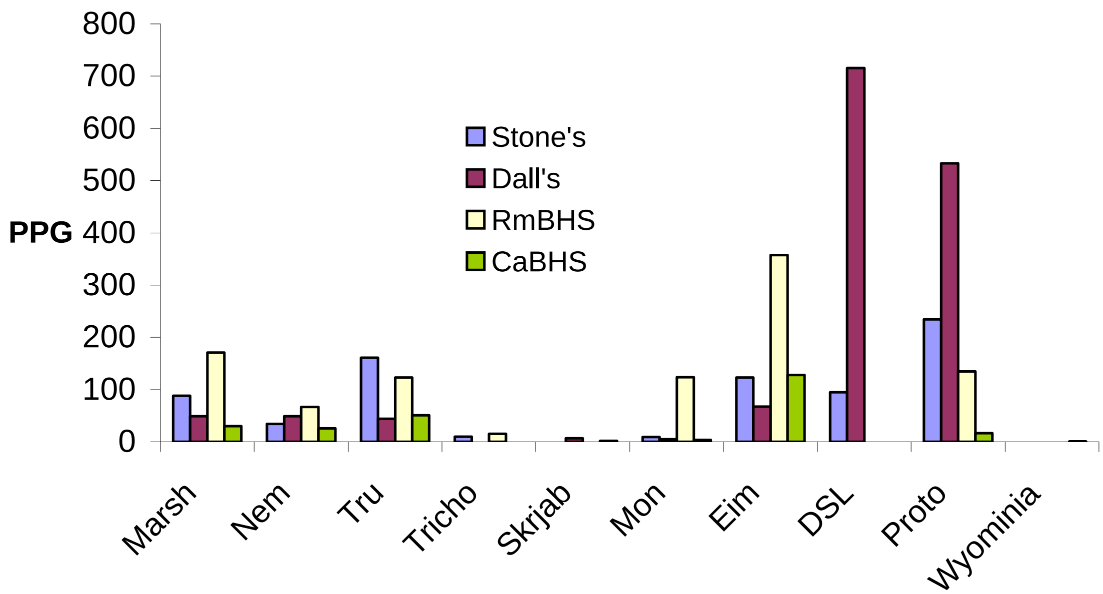

Figure 6: Average intensity (number of parasite eggs or larvae per gram of feces, PPG) for fecal collections from 4 wild sheep populations.

Note that the values for Marsh, Nem, Tru, Tricho, and Skrjab were multiplied by 10 to better demonstrate differences at this scale.

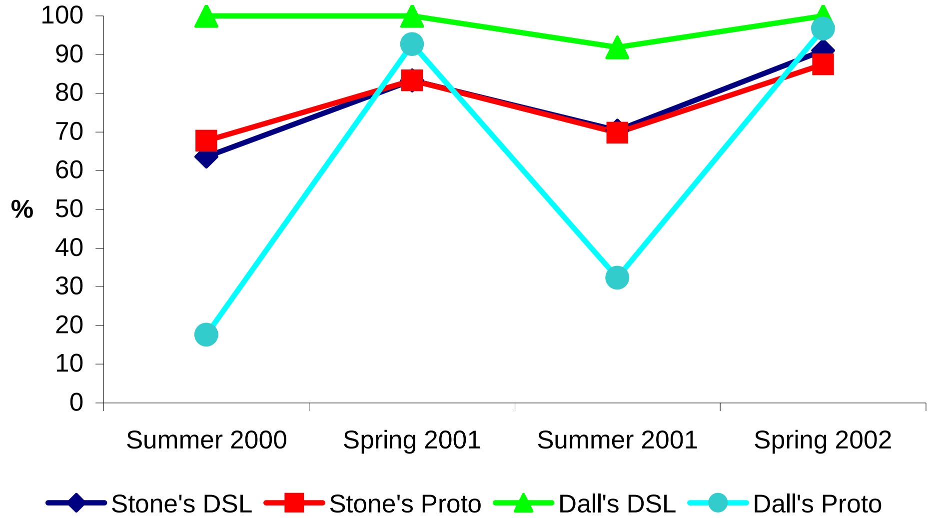

Figure 7: Prevalence of *Protostrongylus* spp. lungworm larvae and dorsal-spined larvae (DSL) of *Parelaphostrongylus odocoilei* in the Muskwa-Kechika Stone's Sheep population and the Mackenzie Mountains' Dall's Sheep population in the four collection periods.

Prevalence is the percent of samples positive for each parasite.

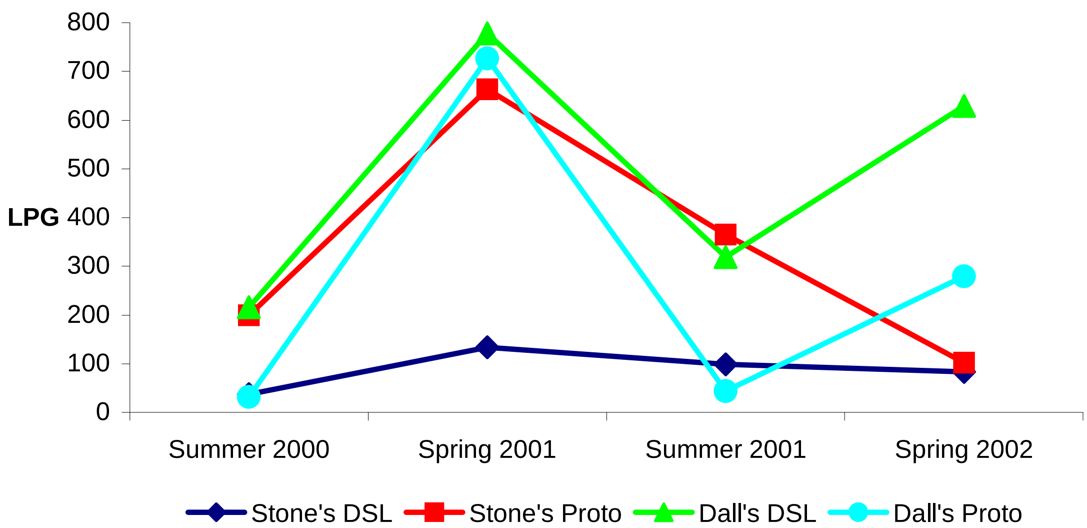

Figure 8: Average intensity of *Protostrongylus* spp. lungworm larvae and dorsal-spined larvae (DSL) of *Parelaphostrongylus odocoilei* in the Muskwa-Kechika Stone's Sheep population and the Mackenzie Mountains' Dall's Sheep population in the four collection periods.

Intensity refers to the number of larvae per gram of feces (LPG).